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# PLOWING AS A MEANS OF DESTROYING WIREWORM PUPAE IN THE PACIFIC NORTHWEST

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## CONTENTS

| | Page |
|---|---|
| Introduction | 1 |
| Experimental methods | 2 |
| Discussion of results | 3 |
| Value of plowing as a control measure | 7 |
| Summary and conclusions | 8 |

## INTRODUCTION

Entomological literature is replete with general recommendations suggesting the utility of plowing fields infested with wireworms during the peak of occurrence of the pupal stage as a possible method of combating these pests. These recommendations are based on the assumption that a large portion of the pupae could be thus destroyed. Little, however, has been published giving in definite figures the effectiveness of this method. Therefore, in order to determine more definitely the number of wireworm pupae that would succumb as a result of plowing, a series of field tests were conducted in wireworm-infested fields of southern Idaho during the period from 1932 to 1934.

In contemplating these tests it was believed that plowing alone, as a method of wireworm control could not be depended upon as a sole means of eliminating these pests in any given field or locality. Moreover, biological studies of the principal wireworms involved have demonstrated that in southern Idaho the seasonal occurrence of the pupae of the different species extends over a total period of at least 30 days. This prolonged period imposes a disadvantage upon any control method directed against the pupae, since at any one time only a portion of the transforming individuals are in a required critical stage of development which would render them susceptible to injury by plowing. Furthermore, only a part of the total cultivated acreage on the farms in any given locality of the Pacific Northwest is ordinarily free from crops, and thus available for plowing, during the period of maximum pupal occurrence. Finally, the destruction of wireworm pupae does not result immediately in measurable benefits because the larval progeny of such individuals would not have reached the destructive stage in any event for at least a year. Because the effects are thus delayed, the plowing treatment lacks the spectacular or immediate effect necessary to impress on affected growers the benefits that might accrue from this method.

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[1] The work reported in this circular was conducted at Parma, Idaho, as a part of the Pacific Northwest wireworm investigations under the direction of M. C. Lane, Walla Walla, Wash. The writer acknowledges the assistance rendered by H. P. Lanchester in the work done in 1932.

The results reported in this circular, however, have indicated that a large proportion of the pupae could be destroyed by timely plowing.

The two principal species of wireworms involved in the tests reported upon in this circular were the sugar-beet wireworm (*Limonius californicus* Mann.) and the Pacific coast wireworm (*L. canus* Lec.). These two species occur abundantly in the irrigated districts of the Pacific Northwest. In general, the former species is of the greater economic importance in this territory, but the latter frequently predominates in soils that have an essentially sandy composition. These species are quite closely related and may be considered as one group insofar as the facts pertaining to their seasonal pupal occurrence are concerned. In the latitude of southern Idaho these wireworms are ordinarily entering the pupal stage during the period from approximately July 15 to August 15. Immediately preceding pupation the larva passes through a prepupal stage characterized by a shortening and thickening of the body.

Although it has not been possible to observe the actual formation of the pupal cell it is probable that its construction is begun before the larva reaches a stage that can be definitely recognized as prepupal. In any event, the pupal cell is formed by the prepupa. During this process the larva rolls from side to side in an upright position, compacting and smoothing the surrounding soil, an action which results in the formation of the walls of the cell. When completed, the pupal cell is about three-fourths of an inch in length, and the pupa is invariably in an erect position within the cell. From extensive field examinations it has been found that the pupal cells occur at an average depth of 6 inches below the soil surface, with individual pupal cells ranging from 3 to 15 inches below the surface. In the tests herein reported the plowing was done to a depth of 9 inches, and in the majority of fields this would disturb or uncover at least 90 percent of the pupae.

Under laboratory conditions the pupal stage has been observed to occupy an average period of 21 days. In the field, where soil temperatures range somewhat higher than in the laboratory, it is probable that the pupal stage would be somewhat shorter, possibly not exceeding an average of 18 days. Since the prepupa is soft and easily injured for a day or two prior to pupation, and since the newly transformed adult requires at least 24 hours to become fully hardened, there is a period of at least 3 weeks during which each transforming wireworm is susceptible to injury from plowing.

## EXPERIMENTAL METHODS

Fields known to be heavily infested with wireworms were selected for the plowing tests. Strips 30 feet wide and approximately 150 feet long were plowed in these fields, and unplowed strips of equal dimensions were left between the plowed strips to serve as checks. The number of plowed strips per field ranged from two to six. The plowing was done during the early part of August, since it was determined by observations extending through several seasons that the pupae were most numerous during that period.

Owing to the limited season in which plowing can be done with maximum effectiveness in destroying wireworm pupae it was not possible to make a survey of these fields before plowing to estimate quantitatively the prospective adult emergence. Observations have shown that an estimate based on the number of pupae and prepupae present would have been unreliable owing to the number that would have been mashed and thus overlooked in the course of the soil-sifting operations incident to taking the samples. Moreover, laboratory observations have shown that some of the larvae which appear to be about to pupate fail to do so, and for this reason it would have been inaccurate to have counted all apparently prepupal wireworms as potential adults. It should be emphasized that the pupae and prepupae are fragile and subject to injury in handling, whereas the wireworm larvae and adults are not fragile and may be readily counted by screening the soil in which they are contained. Hence the final soil examination in both the test and check plots to appraise the effectiveness of the plowing treatment were not made until after the transforming wireworm larvae had become fully hardened beetles.

In checking the results of the plowing tests, counts were made of the elaterids present in unit areas of 1 square foot each taken at random in the plowed and check strips. The soil was examined to a depth of 18 inches which took in practically all of the wireworm larvae as well as the adults under the sample areas and enabled a comparison to be made of the entire elaterid populations in the plowed and in the check strips. To secure uniformity in the size of samples and to prevent soil from crumbling into the hole while the sample was being taken a sheet-iron form having inside measurements of 12 by 12 by 8 inches was used. This form was pressed into the ground and the enclosed soil was removed and screened, and all the elaterids in both adult and larval stages were recorded. A soil-sifting machine[2] driven by a 1-horsepower gasoline engine and having a capacity of 6 to 10 cubic feet of soil per hour was used to facilitate the examinations.

## DISCUSSION OF RESULTS

Some preliminary work in 1932 indicated that there was no increase in mortality of the wireworm pupae when plowing was followed by harrowing. In fact, it appeared that actually fewer pupae were killed when the plowed land was harrowed than when this operation was omitted, and when the ground was plowed twice and harrowed each time after plowing the effectiveness was decreased progressively. This may have been due to the fact that harrowing compacts the soil to some extent and conserves the soil moisture, and thus enables many of the uninjured pupae to complete their transformation to adults, in which stage they are more resistant to the effects of desiccation. In the more extensive experiments carried on in 1933 and 1934 the soil was plowed to a depth of 9 inches and left without further cultivation.

The following tabulation shows the comparative effectiveness of various combinations of treatment in destroying the pupae. In each case the test was repeated four times with a total of 40 samples of 1 square foot examined for each treatment.

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[2] LANE, M. C., and SHIRCK, F. H. A SOIL SIFTER FOR SUBTERRANEAN INSECT INVESTIGATIONS. Jour. Econ. Ent. 21: 934–936, illus. 1928.

——— and SHIRCK, F. H. A MOBILE POWER SOIL SIFTER. U. S. Dept. Agr., Bur. Ent. and Plant Quarantine Circ. ET-70, 2 pp., illus. 1936. [Mimeographed.]

| Treatment: | *Adults surviving* |
|---|---|
| Plowed once only (Aug. 1), not harrowed | 16 |
| Plowed Aug. 1 and harrowed once | 21 |
| Plowed and harrowed Aug. 1 and the same treatment repeated Aug. 5 | 29 |
| Check (unplowed) | 74 |

In making the final field-plot examinations, the surviving larvae and adults were recorded separately. Table 1 presents data on the ability of wireworms to survive summer plowing in 1933 and 1934. Apparently the plowing operation did not cause the death of any significant number of immature larvae. Only about 50 percent of the larvae, other than the prepupae, were in the top 9 inches at the time the plowing was done. The larvae that may have been turned up to the soil surface by the plow evidently succeeded in most instances in returning to lower positions in the soil without encountering critical conditions of heat and desiccation in the inverted soil. Owing to the tough and hardy nature of wireworm larvae only a negligible degree of mechanical injury can be inflicted upon them by plowing or by other ordinary tillage operations.

The data showing the results obtained against wireworm pupae in plowing tests conducted in 1933 and 1934 are also presented in table 1. It will be noted that definite indications of the effectiveness of plowing as a means of eradicating wireworm pupae were obtained.

TABLE 1.—*Effectiveness of plowing as a means of destroying wireworms, Parma, Idaho*

[The check plots in each case were examined the same day as the plowed plots and were represented by the same number of samples]

| Field no. | Date plowed | Date examined | Plots | Samples | Living larvae | | | Living adults | | | Character and condition of soil when plowed [2] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | In check plot | In test plot | Index of effectiveness [1] | In check plot | In test plot | Index of effectiveness | |
| | | | *Number* | *Number* | *Number* | *Number* | *Percent* | *Number* | *Number* | *Percent* | |
| 1 | Aug. 3, 1933 | Aug. 28 | 2 | 50 | 80 | 55 | 31. 2 | 50 | 4 | 92. 0 | Fine sandy loam; dry, cloddy. |
| 2 | Aug. 9, 1934 | Sept. 27 | 4 | 100 | 185 | 104 | 43. 8 | 93 | 12 | 87. 1 | Clay loam; dry, large clods. |
| 3 | Aug. 4, 1934 | Sept. 5 | 4 | 32 | 259 | 261 | —. 8 | 80 | 13 | 83. 8 | Clay loam; moist, mellow. |
| 4 | Aug. 6, 1934 | Sept. 25 | 6 | 96 | 167 | 124 | 25. 7 | 108 | 19 | 82. 4 | Sandy loam; dry, somewhat cloddy. |
| 5 | Aug. 8, 1934 | Sept. 12 | 3 | 75 | 415 | 318 | 23. 4 | 206 | 48 | 76. 7 | Sandy loam; moist, mellow. |
| 6 | Aug. 9, 1934 | Sept. 22 | 4 | 60 | 145 | 126 | 13. 1 | 20 | 6 | 70. 0 | Clay loam; moderately cloddy. |
| 7 | Aug. 4, 1934 | Oct. 4 | 4 | 32 | 197 | 197 | 0 | 84 | 26 | 69. 1 | Clay loam; moist, mellow. |
| 8 | Aug. 4, 1933 | Aug. 29 | 2 | 44 | 124 | 76 | 38. 7 | 88 | 28 | 68. 2 | Sandy loam; dry. |
| 9 | Aug. 2, 1934 | Sept. 18 | 4 | 100 | 124 | 215 | —42. 3 | 330 | 209 | 36. 7 | Loamy sand; dry, ashy. |
| Average | | | | | | | 14. 7 | | | 74. 0 | |

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[1] Minus (—) sign indicates a greater number of larvae in test plot.

[2] The writer is indebted to E. W. Jones, of the Walla Walla laboratory of the Bureau of Entomology and Plant Quarantine, for the soil analyses upon which the soil classes listed in this table were established. The classifications follow those in the following publication: DAVIS, R. O. E., and BENNETT, H. H. GROUPING OF SOILS ON THE BASIS OF MECHANICAL ANALYSIS. U. S. Dept. Agr. Circ. 419, 14 pp., illus. 1927.

The index of effectiveness as used in the table is based upon the difference between the number of living insects found in the plowed and check plots, expressed as a percentage of the population in the check plot. For the reasons stated previously, it was impracticable to make any direct comparison of the number of adults in a given plowed strip before and after treatment.

A subsoiling implement known as a "chisel" was also used in one series of experiments conducted in 1934. This implement, which has a cutting edge 2 inches wide, was drawn through the soil, the marks so formed being 18 inches deep and spaced 24 inches apart. The object of these tests was to determine the effect of tillage upon wireworms that were too deep in the soil to be reached by the moldboard plow. It was hoped that this deep tillage would facilitate the evaporation of moisture from the subsoil layer, and that the soil would in consequence become dry enough to cause the death of a majority of the wireworms contained therein. Careful observations were made after the treatment, and it was found that the "chiseling" treatment was entirely unsuccessful in reducing wireworm populations. Moreover, so far as could be accurately determined, the soil moisture was not affected at any depth by this treatment.

The fields in which the experiments were conducted embrace a variation in type and condition of soil. Referring to table 1 it will be noted that the highest mortality to pupae was obtained in the case of field no. 1. The soil in this field was a fine sandy loam, and was observed to be dry and cloddy when plowed. In field no. 2, where 87.1 percent mortality to pupae was indicated, the plowed ground was extremely cloddy. In the heavier soils the effectiveness of plowing seems to be slightly greater when the soil has become dry, i. e., containing approximately 7 to 10 percent soil moisture, so as to turn up cloddy when plowed. Good results can also be obtained, however, when a heavy soil, such as a clay loam, is plowed in the presence of soil-moisture conditions which, from the standpoint of granulation, are more nearly optimum, ranging in moisture content from 11 to 18 percent. In field no. 3, where plowing was attended by an apparent mortality of 83.8 percent, the plowed ground was mellow and well pulverized.

In general it may be stated that plowing appears less effective on sandy soils than on the heavier soils. Although no complete explanation of this reaction can be offered, two reasons may be suggested: (1) Pupations often occur at a slightly greater depth in the sandier soils since in them, owing to the fact that these soils in the summer are hotter and drier, the wireworms penetrate deeply to find favorable conditions. In field no. 9 (table 1) where the soil is a loamy sand, approximately 50 percent of the adults in the check strips were found between the depths of 8 and 18 inches. (2) Sandy soils offer less resistance to plowing and, consequently, less mechanical injury results to pupae when these soils are plowed.

Mechanical injury suffered during the operation of plowing is doubtless responsible for an important measure of the pupal mortality. The movement and crumbling of the soil as it is turned by the plowshare break up many pupal cells and injure the pupae. The wireworm pupa is very soft, and any rupture in its integument, however slight, usually results fatally. Most of the pupae turned up to the soil surface by the plow were noted to be injured, and doubtless many injured pupae were not exposed to view. In addition, some pupae were probably killed by contact with the hot surface soil turned under by the plow. The maximum surface temperature during the plowing period averaged 125° F. This temperature is known to be lethal to all stages of wireworms, and more especially to those stages incapable of migration. The actual effect of drying on wireworm pupae is problematical, but no doubt some mortality results from exposure to low humidities in addition to that caused by the heat.

Fields planted to different crops have been found to differ markedly in the percentage of a given larval population which transforms to or produces adults. Data taken from several seasons' sampling records are given in table 2, in which the number of adult beetles emerging in different crops are compared. For instance, infestations of elaterids in sugar-beet fields were determined in five instances over a period of 4 years, a total of 125 square-foot samples of soil being examined. In these 125 samples a total of 68 adult beetles were found. In all instances the larval population had fed exclusively on sugar-beet plants, at least during the spring and summer immediately prior to the emergence of adults. The average larval infestation prior to emergence of adults was three wireworms per square foot. The proportion of infestation that emerged as adults is obtained by dividing the total adults obtained by the larvae obtained and multiplying the quotient by 100. This table shows that a given infestation of wireworms will produce more adults under some crops than under others, the proportions of wireworm larvae that emerge as adults being especially low in alfalfa fields and pastures, and higher following such crops as sugar beets and potatoes.

TABLE 2.—*Number of elaterid beetles emerging in different crops from the preceding year's larval population*

| Crop | Plots examined | Total square-foot samples | Larvae obtained | Average larvae per square foot | Total adults obtained | Proportion of infestation that emerged as adults |
|---|---|---|---|---|---|---|
| | *Number* | *Number* | *Number* | *Number* | *Number* | *Percent* |
| Sugar beets | 5 | 125 | 375 | 3.0 | 68 | 18.1 |
| Potatoes | 10 | 250 | 975 | 3.9 | 148 | 15.2 |
| Red clover | 10 | 250 | 650 | 2.6 | 32 | 4.9 |
| Wheat[1] | 9 | 225 | 1,350 | 6.0 | 49 | 3.6 |
| Alfalfa | 21 | 525 | 840 | 1.6 | 17 | 2.0 |
| Pasture | 9 | 225 | 788 | 3.5 | 15 | 1.9 |

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[1] In 8 of the 9 instances shown, the wheat was grown entirely without irrigation or else with insufficient irrigation. Had the crop been irrigated normally, the number of adults would probably have been considerably greater in the case of wheat.

## VALUE OF PLOWING AS A CONTROL MEASURE

Alfalfa, which occupies much of the land not available for August plowing, has been found to produce relatively few beetles as compared with other crops. On the other hand, the number of pupae has been found to be unusually high in potato fields. Consequently, plowing to combat wireworms should always be done following removal of an early potato crop. Such treatment will have a tendency to protect both the field plowed and the fields adjacent thereto from heavy reinfestation by wireworms the year after. The seeding of head lettuce in August following the harvest of early potatoes is a common practice in southern Idaho that allows for deep plowing at the time most opportune for the destruction of wireworm pupae. Following harvest, wheat or barley fields can usually be cleared and made ready for plowing by the first of August, and thus an important contribution to wireworm control can be made.

Unlike many insects, wireworm adults do not migrate extensively. The females normally deposit their eggs in the same field from which they emerge or in adjacent fields. For this reason, destruction of the majority of the pupae in a given field, as shown to be possible in the foregoing experiments, offers a practical means of reducing the number of young wireworms that would otherwise become established in it the following year.

## SUMMARY AND CONCLUSIONS

Studies were made to determine the effect of plowing on wireworm pupae in the irrigated lands of southern Idaho. *Limonius californicus* and *L. canus*, the principal species involved in the tests herein reported, pass about 21 days in the pupal stage, the different individuals entering that condition from about July 15 to August 15.

The larvae and adults are not easily killed, but the pupae are extremely fragile and easily killed by injury, high temperatures, or the drying of the soil.

Plowing to combat wireworms by destroying the pupae should be carried on during the first week of August in southern Idaho. It has been found that on the average approximately 75 percent of the pupae of *Limonius* can be killed by plowing. This represents a practical aid to wireworm control that can be accomplished with no additional expense except that involved in plowing to an average depth not more than 3 inches greater than the plowing depth now in vogue. Apparently the best results are produced by plowing to a depth of 8 or 9 inches and leaving the soil surface rough.

No significant number of immature larvae are killed by ordinary plowing methods. Mechanical injury is apparently responsible for the larger portion of the pupal mortality, supplemented by the effect of exposure to summer heat and low humidities.

Fields that have been in small grain and fields devoted to the production of early truck crops, such as peas and early potatoes, can be plowed during the optimum period for destroying wireworm pupae.

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